Development of Low Thermal Conductivity, Polyacrylonitrile-Based Fibers

Raymond G. Clinton, Jr./EH34
205–544–2682

During the past 6 years, the Materials and Processes Laboratory—in cooperation with the Solid Propulsion Integrity Program and the U.S. solid rocket motor industry—has conducted a research program to develop and evaluate low thermal conductivity, polyacrylonitrile-based carbon fibers as potential replacements for rayon-based carbon fibers currently used as reinforcement for phenolic-matrix composites in solid rocket motor nozzle applications. Progress of the research program has been documented in past volumes of Research and Technology[1] and elsewhere.[2] As part of this ongoing effort, material performance results have been collected from the Reusable Solid Rocket Motor–4 MNASA static motor firing that occurred in the summer of 1994.

Both polyacrylonitrile-based materials tested, FM5950 and FM5952, were prepregged by B.P. Chemicals using Ironsides 91LD phenolic resin. Table 6 offers fiber, fabric, and composite properties and descriptions of these two materials for both MNASA tests. Placement of the test materials in the throat ring and identification of other nozzle components are provided in figure 104. The throat was designed with a split-ring configuration to enable comparison of the two low thermal conductivity, polyacrylonitrile candidates to each other and to a baseline rayon-based ablative (MX4926).

The FM5952 throat section was constructed from material containing the same fiber lot of Amoco T350–25 as used in the Solid Propulsion Integrity Program–3 MNASA nozzle, but a prepreg lot with a lower resin content was used. The FM5950 throat section represented the same Hercules LF–2 fiber lot and the same prepreg lot as used in the Solid Propulsion Integrity Program–3 MNASA, but the piece was postcured to reduce volatile content and to increase its permeability (by causing an increase in matrix microcracking). As can be seen from the data contained in table 085a, the permeability values of these materials as measured at room temperature were significantly higher than the similar materials tested in the Solid Propulsion Integrity Program–3 MNASA. To fully evaluate the criticality of permeability effects,

Table 6.—Low thermal conductivity, polyacrylonitrile materials in the Solid Propulsion Integrity Program–3 and Reusable Solid Rocket Motor–4 MNASA motors.

	FM5950		FM5952	
	SPIP–3	RSRM–4	SPIP–3	RSRM–4
Fiber	LF–2; 6K	LF–2; 6K	T350–25; 6K	T350–25; 6K
Fiber Tensile Strength, Ksi	370	370	351	351
Weave	5HS, 13×13	5HS, 13 ×13	5HS, 13 ×13	5HS, 13 ×13
Shear Treat	Yes	Yes	Yes	Yes
Sizing	GP	GP	UC322	UC322
Specific Gravity	1.62	1.61	1.63	1.61
Resin Content, %	34.0	35.0	33.5	29
Residual Volatiles, %	1.5	1.5 As Cured 0.2 Postcured	1.0	3.9
Postcured	No	Yes*	No	No*
Room Temp. Permeability, Log D'Arcy Constant	–12.2	–11.39	< –20	–13.9
Pocketing	Severe	Severe	Severe	None

* Exposed to overwrap cure after initial cure

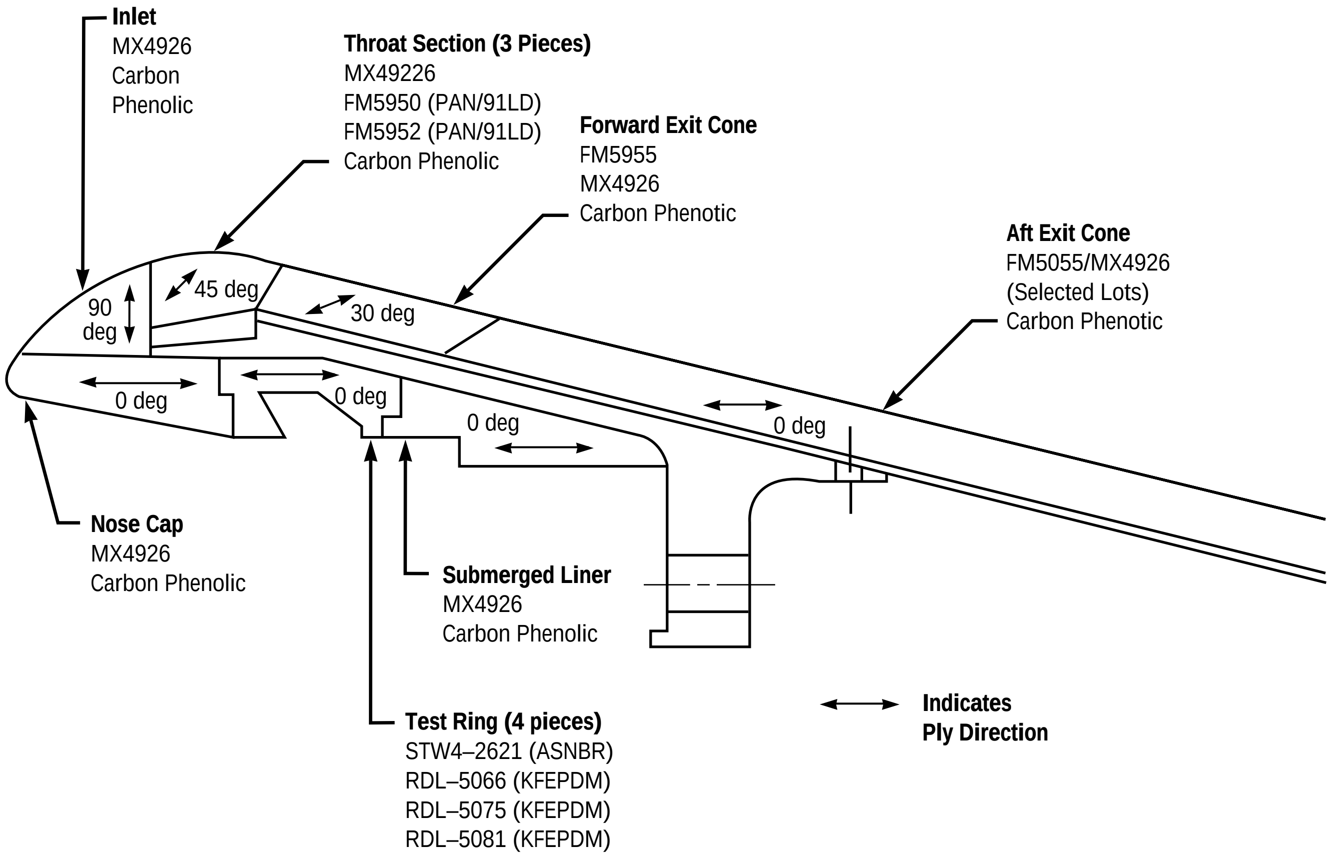

FIGURE 104.—MNASA motor, Reusable Solid Rocket Motor–4, nozzle configuration.

however, more data concerning permeability at the temperatures of the pocketing event are required.

Performance results are summarized as follows. The FM5952 material performed anomaly-free. As the Solid Propulsion Integrity Program–3 MNASA data had suggested—in the absence of pocketing—the low thermal conductivity, polyacrylonitrile-based materials exhibited erosion performance similar to that of the baseline rayon-based ablatives. Using the MSFC check gauge to measure erosion, data were obtained from ten azimuths for the FM5952 and MX4926 sections from the Reusable Solid Rocket Motor–4 MNASA throat. Analysis of these data indicates that the erosion performance of the two materials is statistically indistinguishable at confidence levels exceeding 95 percent. The postcured FM5950 material pocketed as severely as the nonpostcured material in the Solid Propulsion Integrity Program–3 MNASA nozzle, indicating that postcuring does not resolve the polyacrylonitrile pocketing issue. Due to pocketing, erosion measurements for comparison to other throat materials were not made.

A thorough study of potential factors contributing to pocketing was conducted after the Solid Propulsion Integrity Program–3 MNASA tests in an effort to understand the reasons behind, and to appropriately select materials and process conditions to maximize information gained from, the Reusable Solid Rocket Motor–4 MNASA test. In addition to postcuring/permeability, the other variable examined was resin content. (As shown in table 6, the FM5952 resin content was significantly lower than other materials.) The data plotted in figure 105 indicated resin content as an apparent discriminator between materials that have pocketed and those that have not. Reusable Solid Rocket Motor–4 MNASA material performed in accordance with this trend. Also, laboratory-scale tests of these same materials conducted using the nozzle ablative simulation apparatus at Southern Research Institute produced similar results, i.e., the FM5950 pocketed and the FM5952 did not.

Unfortunately, due to the transition/termination of the Solid Propulsion Integrity Program, efforts to fully understand and characterize critical performance drivers and to provide the fundamental science and engineering foundation enabling confident nozzle design with alternate polyacrylonitrile fiber-reinforced ablatives will not be furthered. An excellent summary of the accomplishments in material development and the status of the design potential for polyacrylonitrile-based ablative materials is provided by Emery et al.[3] The most advanced work continuing in this area is being conducted at Thiokol/Wasatch Operations and Alliant Techsystems, Inc./Bacchus Works.

[1]Clinton, R.G., 1994. Development of Low Thermal Conductivity, Polyacrylonitrile-Based Fibers for Solid Rocket Motor Nozzle Applications. *Research and Technology 1994*.

[2]Hill, K.H.; Wendel, G.M.; and Tillery, S.W. November 1994. Applicability of Polyacrylonitrile-Based Carbon Phenolic to Solid Rocket Motor Nozzles. Joint Army, Navy, NASA, and Air Force Rocket Nozzle Technology Subcommittee Meeting. Boeing Defense and Space Group, Kent, Washington.

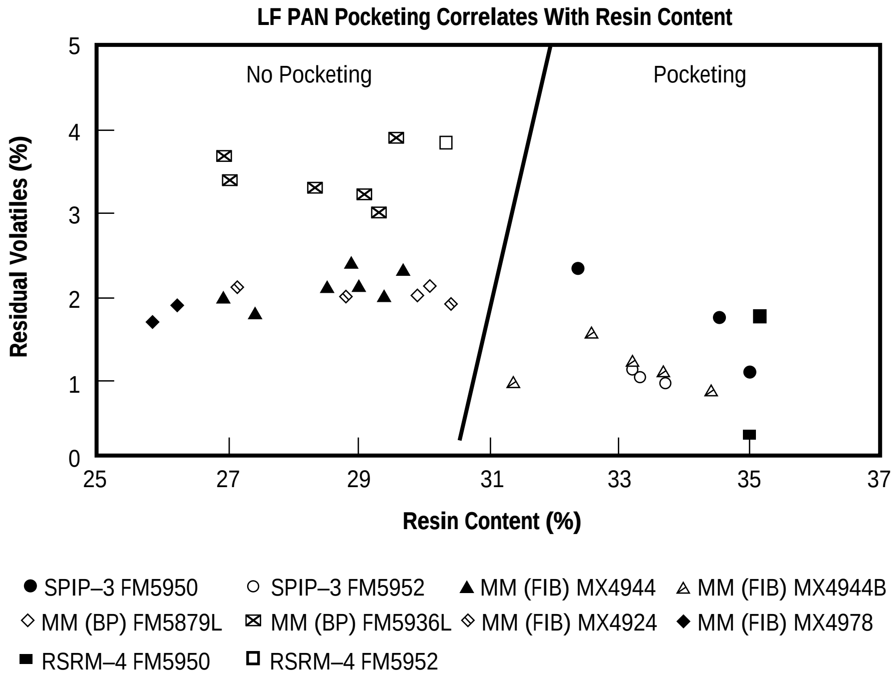

FIGURE 105.—Pocketing versus resin content and residual volatiles.

[3]Emery, E.A.; Heyborne, C.M.; Hill, K.H.; York, J.L.; Canfield, A.R.; Thompson, A.P.; and Wendel, G.M. December 1994. Assessment of the Design Potential of Polyacrylonitrile-Based Materials for Ablative Applications. Solid Propulsion Integrity Program Final Report, Document HI–070F/1.2.9.

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